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CLOSED CYCLE BRAYTON PROPULSION SYSTEM

WITH DIRECT HEAT TRANSFER

TO ALL WHOM IT MAY CONCERN

BE IT KNOWN THAT PAUL M. DUNN, citizen of the United States of America, employee of the United States Government and resident of Wakefield, County of Washington, State of Rhode Island has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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CLOSED CYCLE BRAYTON PROPULSION SYSTEM WITH DIRECT HEAT TRANSFER

This patent application is copending with the related applications by the same inventor filed on the same date as subject patent entitled Closed Brayton Cycle Direct Contact Reactor/Storage Tank with Chemical Scrubber, ~~identified as Navy Case No. 72910~~ Serial No. 07/926,090, filed 7 August 1992, Closed Brayton Cycle Direct Contact Reactor/Storage Tank with ~~Q~~ O2 Afterburner, ~~identified as Navy Case No. 72939~~ Serial No. 07/926,200, filed 7 August 1992, ~~Closed Cycle Brayton~~ Semiclosed Brayton Cycle Power System with Direct Heat Transfer, ~~identified as Navy Case No. 73348,~~ Serial No. 07/926,199, filed August 7, 1992 and Semiclosed Brayton Cycle Power System with Direct Combustion Heat Transfer, ~~identified as Navy Case No. 73825~~ Serial No. 07/926,115, filed August 7, 1992.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The invention relates generally to non-air breathing power systems and, in particular, to a closed Brayton cycle propulsion system using direct heat transfer.

(2) Description of the Prior Art

Torpedoes and other underwater vehicles use propulsion systems having turbines powered by the reaction of an oxidant with a metal fuel in a liquid state, hereinafter referred to as liquid metal fuel, as a heat source. Lithium or another alkali metal is commonly used as liquid metal fuel with sulphur hexafluoride, SF_6, as the oxidant. A chlorofluorocarbon, such as $C_2F_3Cl_3$ known in the art as Freon-13, can also be used as the oxidant. Another possible liquid metal fuel is an aluminum-magnesium alloy with O_2 as the oxidant. Chlorofluorocarbons cannot be used with an aluminum-magnesium fuel because AlCl, one of the products of the reaction, is gaseous at operating temperatures.

Current underwater propulsion systems are typically closed Rankine cycle power systems utilizing lithium as a liquid metal fuel, a chlorofluorocarbon as an oxidant, and water as a working fluid. In a typical Rankine system, the working fluid is compressed, heated until vaporization, and then expanded through a turbine to produce power. Upon exiting the turbine, the low pressure vapor is condensed to a liquid, and the cycle is repeated. The working fluid is heated as it passes through heat transfer tubes that are wrapped to form a cylindrical annulus within the system's heat exchanger. Liquid metal fuel is contained in the center of the cylinder in order to heat the working fluid being carried by the heat transfer tubes. The working fluid, water, and the liquid metal fuel, lithium, react

chemically with one another. A leak in the heat transfer tubes causes a violent reaction which generates a significant amount of heat and gas causing the heat exchanger and the underwater device to fail. Furthermore, should a leak occur in a land-based system, a toxic cloud of LiOH will be released into the environment. Other problems associated with the Rankine cycle include noise generation during the phase change of the working fluid, severe stress of the oxidant's injectors due to high reaction zone temperatures, and slow start-up time.

An alternative to the closed cycle Rankine system is the closed Brayton cycle system. In a Brayton cycle, there is no phase change and accordingly, no noise associated therewith. The Brayton cycle is also more efficient than the Rankine cycle despite the fact that more energy is required to compress a gas than to pump an equivalent mass of liquid. Prior art Brayton cycle systems cannot be used in underwater systems because the components of the closed Brayton cycle, principally the conventional Brayton heat exchanger, are too large to be used in the restricted space available in underwater vehicles.

A compact heat exchanger can be made by increasing gas velocity to achieve higher heat transfer coefficients; however, this results in greater heat exchanger pressure drop. This method is used successfully in the Rankine cycle since pump power is a small fraction of gross power (1/50) and pump losses are small by comparison. Accordingly, there is no significant reduction in cycle efficiency. In the Brayton cycle, however,

compressor power is typically a large part of the gross power (1/2); therefore, small increases in gas velocity and heater pressure drop reduce the Brayton cycle efficiency below that of the Rankine cycle.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a closed Brayton cycle power system for use in an underwater vehicle propulsion system.

Another object of the present invention is to provide a closed Brayton cycle power system that utilizes a compact heat exchanger with low pressure drop.

Another object of the present invention is to provide a closed Brayton cycle power system that will propel an underwater vehicle for longer periods of time.

In accordance with the present invention, a liquid metal fueled Brayton cycle power system is used to power an underwater device. A compressor is provided to compress the working gas. The compressed working gas is then preheated in a regenerator and passed to a reactor/storage tank. Liquid metal fuel is stored within the reactor/storage tank. An oxidant is injected into the reactor/storage tank to react with the liquid metal fuel and thereby generate heat. The compressed working gas is bubbled through the liquid metal fuel/oxidant mixture and heated by direct contact. A turbine is provided for expanding the working gas and withdrawing power from the system. The working gas is cooled and recirculated.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein:

FIG. 1 is a schematic drawing depicting a closed Brayton cycle system; and

FIG. 2 is side sectional view of a direct contact reactor/storage tank configuration according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a closed cycle Brayton propulsion system **10** used to turn a drive shaft **12**. A compressor **14** driven by shaft **12** compresses a working gas. A regenerator **16** for preheating the working gas is placed in communication with the high pressure end of compressor **14**. The output of regenerator **16** is operatively connected to carry the warmed gas to a reactor/storage tank **18** and an oxidant mixing valve **20**. An oxidant storage tank **22** controlled by an oxidant control valve **24** is in communication with an injector **26** in reactor/storage tank **18**. Injector **26** injects an oxidant into the reactor/storage tank where the oxidant reacts with the liquid metal fuel to produce heat. Oxidant mixing valve **20** acts to mix part of the warmed working gas with the oxidant to cool the temperature at injector **26**.

Reactor/storage tank **18** is partially filled with liquid metal fuel. The warmed working gas enters reactor/storage tank **18** through working gas inlet tube **28** positioned below the surface of the liquid metal fuel in reactor/storage tank **18**. A working gas outlet **30** is positioned in reactor/storage tank **18** above the surface of the liquid metal fuel. A turbine **32** is connected with working gas outlet **30** to receive the heated, high pressure, working gas.

Turbine **32** expands the working gas and mechanically transmits the extracted energy through drive shaft **12**. Low pressure working gas from turbine **32** is transferred to regenerator **16** where the hot, low pressure working gas can transfer its heat to the cool, high pressure working gas passing from compressor **14** to reactor/storage tank **18**. Low pressure gas exits from regenerator **16** and passes to a cooler **34** where the working gas is cooled by contact with the environment. In the preferred embodiment seawater is used to cool the working gas. Cool low pressure working gas is transported from cooler **34** to compressor **14**.

An accumulator **36** having an accumulator input valve **38** and an accumulator output valve **40** is shown in communication between the compressor **14** output and input. Accumulator **36** can be initially filled with the working gas under pressure prior to initiation of the cycle. At start up, accumulator output valve **40** is opened to allow the working gas to enter the system. At any time during operation when the compressed working gas has

higher pressure than the gas in accumulator **36**, the power to the system can be reduced by opening accumulator input valve **38** and withdrawing working gas from the system.

Compressor **14** is mechanically connected to receive power from turbine **32** via drive shaft **12** mechanically connected to turbine **32**. A drive means or other power consuming device can also be mechanically connected to receive power from drive shaft **12**.

Referring now to FIG. 2, there is shown a detail view of the reactor/storage tank **18** of the current invention. Reactor/storage tank **18** is a tank partially filled with liquid metal fuel **42**. Oxidant injector **26** and working gas inlet tube **28** are disposed below the surface of liquid metal fuel **42**. Oxidant injector **26** is preferably made from tungsten. Working gas inlet **28** is a tube with a plurality of apertures **28a** along the length thereof to disperse the working gas evenly through liquid metal fuel **42**. Representative working gas bubbles **43** are shown leaving aperture **28a** and expanding toward the surface of liquid metal fuel **42**. Working gas outlet **30** is disposed above the surface of liquid metal fuel **42**. A filter **44** and a screen **46** are disposed above the surface of fuel **42** between working gas outlet **30** and the surface. Filter **44** and screen **46** cover the entire surface of the fuel to prevent fuel and contaminants from entering working gas outlet **30**. Screen **46** is typically stainless steel or another refractory metal. Filter **44** is typically a ceramic fiber insulation filter.

The preferred fuel is an aluminum-magnesium alloy. The oxidant in the preferred embodiment is O_2, and the preferred working gas is a mixture of helium, and xenon. The mixture of helium and xenon is preferred because of its heat transfer characteristics; however, argon is frequently substituted for the helium-xenon mixture for economic reasons. The working gas used should have a molecular weight of 20 to 50 grams/mole and be chemically inert with respect to the oxidant and fuel. The selected percentage of helium, argon and xenon used is dependent upon several factors including machinery size, pressure drop in reactor/storage tank **18** versus heat transfer, and performance capabilities of regenerator **16** and cooler **34**.

The pressure of the inert gas mixture must be low enough to allow sufficient dwell time for proper heat transfer and to minimize splashing of liquid metal fuel **42** at its surface.

In operation, after the metal fuel is heated to the liquid state, the working gas is ejected through working gas inlet **28** into reactor/storage tank **18** where the working gas bubbles through liquid metal fuel **42**. Thus, heat is transferred directly from liquid metal fuel **42** to the working gas. The liquid metal fuel **42** is maintained at a bulk temperature slightly above the required turbine inlet temperature.

The oxidant is directly injected from oxidant tank **22** into liquid metal fuel **42** through oxidant injector **26**. The oxidant is substantially consumed by reaction with liquid metal fuel **42**, and, thus, little of the oxidant will exit through working gas

outlet **30**. The oxidant must be stored in oxidant tank **22** and supplied at a high pressure since the oxidant will not pass through compressor **14**. The products of the reaction sink to the bottom of reactor/storage tank **18** where they will not interfere with combustion or the flow of working gas. Furthermore, the products of the liquid metal/oxidant reaction must provide substantially the same volume as the fuel alone.

Temperatures caused by the oxidizing reaction near injector **26** can be in excess of 8,000°F. To prevent excessive injector wear, the oxidant can be mixed with a portion of the working gas using oxidant mixing valve **20** before injection into reactor/storage tank **18** to reduce the injection plume temperature.

The advantages of the present invention are numerous. Since the working gas and liquid metal fuel are inert with respect to each other, direct contact heating is made possible. Thus, heating efficiency is greatly increased over prior art devices which utilize heat transfer tubes coiled within a reactor. In addition, there is no danger of an explosive reaction between the working gas and the liquid metal fuel. Thus, the resulting closed Brayton cycle propulsion system is safer for the environment than the currently used lithium/water Rankine cycle system.

The working gas can be used to control the temperature of the liquid metal fuel at the injector. By reducing temperatures at the oxidizing agent injectors, the useful life of the system

is increased and system cost is decreased. In addition, all noise associated with phase change is eliminated by using a closed Brayton cycle.

The invention disclosed herein may be practiced other than as specifically disclosed. For example, the accumulator can be omitted, the regenerator and cooler may differ structurally from those disclosed herein, and the inert gas/oxidant mixing system can be omitted if the injector can withstand the reactor temperatures.

Thus, it will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.